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HUMAN MILK AND HUMAN MILK BANKS: ADVANCES, CHALLENGES, AND INNOVATIONS IN NEONATAL FOOD CONSERVATION AND SAFETY

LEITE HUMANO E BANCOS DE LEITE HUMANO: AVANÇOS, DESAFIOS E INOVAÇÕES NA CONSERVAÇÃO E SEGURANÇA ALIMENTAR NEONATAL

LECHE MATERNA Y BANCOS DE LECHE MATERNA: AVANCES, DESAFÍOS E INNOVACIONES EN LA CONSERVACIÓN Y SEGURIDAD DE LOS ALIMENTOS NEONATALES

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ABSTRACT

Human milk is recognized as the gold standard of neonatal nutrition, especially for premature newborns, due to its nutritional composition and numerous bioactive components with immunological, anti-inflammatory, and metabolic functions. In this context, Human Milk Banks (HMBs) play a fundamental role in promoting, protecting, and supporting breastfeeding, as well as in the collection, processing, quality control, and safe distribution of donated human milk. This study consists of a narrative literature review aiming to analyze the composition and benefits of human milk, the importance of breastfeeding in premature infants, the role of HMBs, and the conservation methods used, with an emphasis on emerging technologies such as lyophilization. The search was conducted in the PubMed, SciELO, and Google Scholar databases, including articles published between 1980 and 2024. The analyzed studies show that, although Holder pasteurization is effective in ensuring microbiological safety, it can partially compromise heat-sensitive components of human milk. In this scenario, lyophilization emerges as a promising alternative, capable of extending the stability, shelf life, and preservation of the bioactive properties of human milk, as well as facilitating storage and distribution. It is concluded that human milk banks remain essential pillars of neonatal public

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health and that investment in technological innovation, combined with scientific research, is strategic for optimizing the conservation and utilization of donated human milk.

Keywords: Breastfeeding. Human Milk Bank. Prematurity. Lyophilization. Human Milk Preservation.

RESUMO

O leite humano é reconhecido como o padrão-ouro da alimentação neonatal, especialmente para recém-nascidos prematuros, em virtude de sua composição nutricional e de seus inúmeros componentes bioativos com funções imunológicas, anti-inflamatórias e metabólicas. Nesse contexto, os Bancos de Leite Humano (BLH) desempenham papel fundamental na promoção, proteção e apoio ao aleitamento materno, bem como na coleta, processamento, controle de qualidade e distribuição segura do leite humano doado. O presente estudo consiste em uma revisão narrativa da literatura com o objetivo de analisar a composição e os benefícios do leite humano, a importância do aleitamento em prematuros, a atuação dos BLHs e os métodos de conservação utilizados, com ênfase em tecnologias emergentes como a liofilização. A busca foi realizada nas bases PubMed, SciELO e Google Acadêmico, incluindo artigos publicados entre 1980 e 2024. Os estudos analisados evidenciam que, embora a pasteurização Holder seja eficaz na garantia da segurança microbiológica, ela pode comprometer parcialmente componentes termo-sensíveis do leite humano. Nesse cenário, a liofilização surge como uma alternativa promissora, capaz de ampliar a estabilidade, a vida útil e a preservação de propriedades bioativas do leite humano, além de facilitar o armazenamento e a distribuição. Conclui-se que os BLHs permanecem como pilares essenciais da saúde pública neonatal e que o investimento em inovação tecnológica, aliado à pesquisa científica, é estratégico para otimizar a conservação e o aproveitamento do leite humano doado.

Palavras-chave: Aleitamento Materno. Banco de Leite Humano. Prematuridade. Liofilização. Conservação do Leite Humano.

RESUMEN

La leche materna es reconocida como el estándar de oro en nutrición neonatal, especialmente para recién nacidos prematuros, debido a su composición nutricional y numerosos componentes bioactivos con funciones inmunológicas, antiinflamatorias y metabólicas. En este contexto, los Bancos de Leche Humana (BLH) desempeñan un papel fundamental en la promoción, protección y apoyo de la lactancia materna, así como en la recolección, procesamiento, control de calidad y distribución segura de la leche humana donada. Este estudio consiste en una revisión narrativa de la literatura que busca analizar la composición y los beneficios de la leche humana, la importancia de la lactancia materna en prematuros, el papel de los BLH y los métodos de conservación utilizados, con énfasis en tecnologías emergentes como la liofilización. La búsqueda se realizó en las bases de datos PubMed, SciELO y Google Scholar, incluyendo artículos publicados entre 1980 y 2024. Los estudios analizados muestran que, si bien la pasteurización Holder es efectiva para garantizar la seguridad microbiológica, puede comprometer parcialmente los componentes termosensibles de la leche humana. En este escenario, la liofilización surge como una alternativa prometedora, capaz de prolongar la estabilidad, la vida útil y la conservación de las propiedades bioactivas de la leche materna, además de facilitar su almacenamiento y distribución. Se concluye que los bancos de leche materna siguen siendo pilares esenciales de la salud pública neonatal y que la inversión en innovación tecnológica, combinada con la investigación científica, es estratégica para optimizar la conservación y el uso de la leche materna donada.

Palabras clave: Lactancia Materna. Banco de Leche Materna. Prematuridad. Liofilización. Conservación de la Leche Materna.

1 INTRODUCTION

Breastfeeding is recommended as the safest and most complete form of infant feeding due to its nutritional, immunological and functional profile. Several scientific evidences demonstrate that human milk contributes to a significant reduction in neonatal morbidity and mortality, preventing infectious diseases, necrotizing enterocolitis, respiratory disorders, and chronic conditions throughout life (1–3). In addition, it favors cognitive development, promotes affective bonding between mother and baby, and reduces maternal risks such as breast cancer, ovarian cancer, and type 2 diabetes (4).

The importance of human milk is particularly evident among preterm infants, who have gastrointestinal immaturity, low birth weight, immunological vulnerability, and a higher risk of serious neonatal complications. For these infants, human milk (whether from the mother or donated) can halve the risk of necrotizing enterocolitis and improve clinical outcomes (5).

In this context, Human Milk Banks (HMB) have been consolidated as essential components of neonatal care. Brazil has the largest and most complex network of HMBs in the world, internationally recognized for its efficiency, microbiological safety and impact on public health. In addition to milk collection and processing, HMBs promote, protect, and support breastfeeding through specialized care for nursing mothers (6).

Although pasteurization is the most widely used method, limitations related to storage time and partial loss of thermosensitive components have motivated the development of new technologies. Freeze-drying is a promising alternative for preserving the bioactive properties of human milk, expanding its availability in regions with structural limitations (7,8).

In view of this, the present study sought to review the components of human milk, the role of HMBs, the preservation methods used and the perspectives related to the advancement of conservation technologies, with a focus on freeze-drying.

2 MATERIAL AND METHODS

This study is a narrative review of the literature. The search was carried out in the PubMed, SciELO and Google Scholar databases. The keywords used included: "human milk", "breastfeeding", "human milk bank", "preterm infants", "freeze-dried human milk", "lyophilization", "bioactive compounds in breast milk". Articles published between 1980 and 2024 were included, considering original studies, systematic reviews, clinical trials, and official documents from international organizations.

The inclusion criteria included articles that addressed the composition of human milk, the benefits of breastfeeding, the role of HMBs, milk processing, pasteurization, freeze-drying, and the impact of human milk on preterm infants. Articles that did not have a direct relationship with the theme were excluded after reading the title and abstract. The selected texts were analyzed in their entirety to extract the most relevant information.

3 RESULTS AND DISCUSSION

Human milk is a highly complex biological fluid, whose dynamic composition reflects physiological adaptations aimed at meeting the nutritional and immunological needs of the newborn, and is widely described in the literature as a liquid functional tissue whose variability responds to the stage of lactation and to maternal and neonatal characteristics (1,2). From colostrum to mature milk, its constitution changes according to the stage of lactation, gestational age, and maternal-infant physiological stimuli; colostrum stands out for its high concentration of secretory immunoglobulin A, lactoferrin, lysozyme, oligosaccharides and anti-inflammatory cytokines, conferring immediate protection to the newborn and contributing to the maturation of the intestinal immune system (2,13,14). As lactation evolves, transitional milk and mature milk begin to present balanced levels of proteins, carbohydrates, lipids, minerals, vitamins, antimicrobial factors, hormones and living cells, establishing a continuous defense and nutrition mechanism (1,9).

The presence of more than 200 types of oligosaccharides, known as human milk oligosaccharides (HMOs), has been widely documented as one of the most relevant components in the modulation of infant gut microbiota; these oligosaccharides act as natural prebiotics, favoring the growth of Bifidobacterium spp., preventing the adhesion of pathogenic bacteria to the intestinal epithelium, and modulating the neonatal immune response (24,25,9). Alongside HMOs, molecules such as lactoferrin, lysozyme, mucins and immunoglobulins play an essential role in fighting pathogens, promoting protection against gastrointestinal and respiratory infections and participating in the regulation of local inflammation (12,14,15).

Regarding neurological development, the lipids present in human milk, especially long-chain polyunsaturated fatty acids such as DHA and ARA, have a determining influence on myelination, retinal development, and synapse formation; this lipid composition, which is superior in bioavailability when compared to infant formulas, demonstrates a strong association with better cognitive outcomes in breastfed children (24,27). The cellular complexity of human milk is also noteworthy: it contains macrophages, T and B lymphocytes, neutrophils, and stem cell populations that actively participate in immune modulation and can exert systemic effects on child development (13,15). In addition, the microbiota present in human milk, composed of genera such as *Lactobacillus, Bifidobacterium, Streptococcus, and Curtobacterium*, contributes to establishing the infant's intestinal microbiota, reducing colonization by pathogenic microorganisms and strengthening immune barriers (9).

Given this extraordinary composition, it is not surprising that human milk has a superior clinical impact in different neonatal settings; This is particularly evident in preterm infants and low-birth weight infants, whose immature immune system requires a constant supply of functional nutrients and immunomodulatory molecules, and several studies have shown that preterm infants fed with human milk have a lower incidence of necrotizing enterocolitis, late-onset sepsis, bronchopulmonary dysplasia, and retinopathy of prematurity, in addition to a more stable clinical evolution, better digestive tolerance, and shorter hospital stay(5,23,30). The significant reduction in neonatal mortality among preterm infants fed with human milk reinforces the irreplaceable role of this biological fluid (3,5).

In the context of the impossibility of direct breastfeeding, Human Milk Banks (HMB) emerge as essential structures to ensure that hospitalized babies receive safe human milk; in Brazil, the Brazilian HMB Network stands out worldwide for its organization, standardization and comprehensiveness, carrying out activities of home and hospital collection, screening, processing, pasteurization and microbiological analysis of each batch of human milk, ensuring that only safe and adequate products reach newborns (6,18). Pasteurization by the Holder method, a globally used standard, is effective in eliminating pathogenic microorganisms; however, its main limitation lies in the reduction of the activity of thermosensitive compounds, including some immunoglobulins, cytokines, enzymes and cellular components, which has been the subject of several comparative evaluations (10,20).

This limitation has driven research aimed at more effective alternative preservation methods. Among these, freeze-drying has received increasing prominence due to its ability to remove water by sublimation at low temperatures, more effectively preserving the structural integrity of proteins and bioactive components. Recent evidence shows that freeze-dried human milk has greater physicochemical stability, superior retention of secretory immunoglobulin A and lactoferrin, protection of polyunsaturated fatty acids, and maintenance of several anti-inflammatory factors when compared to pasteurized and frozen milk alone (7,8,11). In addition, freeze-drying significantly extends the shelf life of human milk, enabling storage for months without the need for a cold chain, which favors logistics and distribution, especially in remote regions or with limited infrastructure (8,11).

Although promising, the implementation of freeze-drying in HMBs requires standardization of protocols, regulatory analyses, and cost-benefit studies, since the equipment and process require high initial investments and adaptation of laboratory routines; Even so, the scientific literature indicates that the adoption of this technology represents a significant advance for the preservation of human milk, especially for hospital use in high-risk preterm infants (11,21,30). Thus, the scientific development around human milk shows that its value goes beyond the nutritional scope, integrating immunological, microbiological, metabolic and clinical aspects, which together support its position as the ideal food for newborns and reinforce the importance of strengthening public breastfeeding policies and investing in advanced technologies to ensure maximum preservation of the properties of this vital fluid (3,6).

The findings of this review consistently reinforce that human milk is a unique biological fluid, whose complexity goes far beyond the nutritional function, acting as a true immune, metabolic, and microbiological modulator of the newborn. The literature reviewed demonstrates that its bioactive components — including immunoglobulins, cytokines, human milk oligosaccharides (HMOs), immunocompetent cells, and polyunsaturated fatty acids — play a decisive role in protecting against infections, in the maturation of the gastrointestinal tract, and in neurological development, especially in premature infants.

In this scenario, Human Milk Banks emerge as strategic structures of public health, particularly in countries such as Brazil, where the HMB network has wide capillarity and international recognition. The performance of these services goes beyond the simple distribution of human milk, encompassing actions to promote breastfeeding, health education and guarantee microbiological safety, directly impacting the reduction of neonatal morbidity and mortality.

However, the need to ensure health safety through Holder pasteurization imposes challenges related to the preservation of thermo-sensitive components of human milk. Studies indicate variable losses in the biological activity of immunoglobulins, enzymes, and cytokines, which raises the search for alternative or complementary methods of conservation. In this context, freeze-drying emerges as an innovative and promising technology, since it allows greater physicochemical stability, better preservation of bioactive proteins and lipids, and extended storage time without strict dependence on the cold chain.

Despite favorable experimental results, the incorporation of freeze-drying into the HMB routine still faces technical, regulatory, and economic challenges. The scarcity of robust clinical studies evaluating neonatal outcomes directly associated with the use of freeze-dried human milk, as well as the need for standardization of protocols, limits its immediate application on a large scale. Thus, while the available data support its potential, the technology should be seen as complementary to current practices, rather than a substitute, until additional evidence is consolidated.

4 CONCLUSION

The present review shows that human milk remains the gold standard of neonatal feeding, especially for premature and low birth weight newborns, due to its complex bioactive composition and its widely documented protective effects. Human Milk Banks play a central role in ensuring safe access to this biological resource, configuring themselves as fundamental pillars of public policies for maternal and child health.

Technological advances in the conservation of human milk, especially freeze-drying, represent an innovative and promising perspective to expand the availability, stability and distribution logistics of donated human milk. However, the adoption of this technology requires investments, specific regulation and, above all, more clinical evidence that confirms its direct benefits on neonatal outcomes.

It is concluded that the strengthening of HMBs, combined with the encouragement of scientific research and technological innovation, is essential to ensure the maximum preservation of the properties of human milk and to promote continuous improvements in neonatal care. Human milk, in its nutritional, immunological and social dimensions, remains irreplaceable, and its proper management constitutes a strategic priority for contemporary public health.

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